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Calibration of light-flavour jet b -tagging rates on ATLAS proton-proton collision data at $\sqrt{s} = 13$ TeV

A variety of algorithms have been developed to identify jets originating from b -quark hadronization within the ATLAS experiment at the Large Hadron Collider. We describe two measurements of the misidentification rate of jets containing no b - nor c -hadrons for the algorithm most commonly used in the LHC Run 2 ATLAS analyses. The measurements are performed in various ranges of jet transverse momenta and pseudorapidities based on proton-proton collision data collected at a centre-of-mass energy of $\sqrt{s} = 13$ TeV during the year 2015 and 2016. The first measurement is based on a data sample enriched in jets originating from light-flavour quark and gluon hadronization with the application of a dedicated algorithm reversing some of the criteria used in the nominal identification algorithm. The second measurement is based on a bottom-up approach where the underlying tracking variables in the simulation are adjusted to match the data. The effect is then propagated to the high-level observables relevant for b -identification. The results of both methods are found in good agreement and compared to the misidentification rate predicted by the nominal ATLAS simulation in order to calibrate it.

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4

The ATLAS Collaboration

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32 1 Introduction

33 The identification of jets originating from the hadronization of a *b*-quark (*b*-tagging) is an important
34 element of a number of prominent analyses performed with the ATLAS detector [1] at the Large Hadron
35 Collider (LHC): measurements of standard model processes aiming to constrain the heavy-flavour (HF)
36 parton density functions [2], studies of the top quark [3] and the Higgs-boson [4, 5], and exploration of
37 New Physics scenarios [6, 7].

38 The *b*-tagging of a jet relies on the property of the *b*-hadrons to have long lifetime τ ($\tau \sim 1.5$ ps,
39 corresponding to a proper decay length of about $c\tau \sim 450 \mu\text{m}$) and large mass, resulting in the production
40 of tracks with non-zero impact parameters, secondary decay vertices and a large multiplicity of decay
41 products inside the jet cone. These observables are reconstructed with the help of the charged-particle
42 tracking capability of the ATLAS inner detector [8]. The information is then combined using a multi-
43 variate algorithm able to enhance the discrimination of a jet containing *b*-hadrons (*b*-jet) with respect
44 to one containing only *c*-hadrons (*c*-jet) or one containing none of them (LF-jet, LF standing for light-
45 flavour). Specific selections on the output weight distribution of a given *b*-tagging algorithm are called
46 working points (WP) and defined as a function of the average efficiency of tagging a *b*-jet as measured in
47 a $t\bar{t}$ simulated sample [9, 10]. The algorithm most commonly used in the Run 2 ATLAS analyses is called
48 MV2. It assigns to each jet a *b*-tagging discriminant variable ranging from -1 to 1. LF-jets (*b*-jets) MV2
49 distribution peaks towards -1 (1) whereas the *c*-jets lie between the two. The 2016 version of MV2, which
50 is the one considered in this document, is trained with a background sample including 7% of *c*-jets and
51 93% of LF-jets and denoted MV2c10 in the following.

The performance of a b -tagging algorithm is characterised by the probability of tagging a b -jet (ε_b) and the probabilities of mistakenly tagging as a b -jet a c -jet (ε_c) or a LF-jet (ε_l), referred to as “mistag rates” in the following. Ideally, Monte Carlo (MC) simulations including the various quark flavours could be used to evaluate the b -tagging performance. However, additional calibration is often needed to account for differences between data and simulation, originating for instance from an imperfect description of the geometry of the detector. In practice, each working point of the algorithm is calibrated as a function of the jet transverse momentum (p_T^{jet}) and absolute pseudorapidity ($|\eta^{\text{jet}}|$).¹

This document presents the measurements of the LF-jet mistag rate on ATLAS proton-proton collision data recorded at a center-of-mass energy of $\sqrt{s} = 13$ TeV for the MV2c10 WP listed in Table 1 [11] using two methods giving consistent results, the negative tag and the adjusted MC. The negative tag method consists in measuring the LF-jet mistag rate from a high statistics data sample enriched in LF-jets with the application of a dedicated algorithm reversing some of the criteria used in the nominal identification algorithm. The adjusted-MC method is based on a bottom-up approach where the underlying tracking variables are adjusted to match the data and the effect is then propagated to the b -tagging observables. The calibration of b - and c -jet performance is described in separate documents [bCalib_intNote, cCalib_Wc_intNote, cCalib_tt_intNote].

Table 1: b -tagging MV2c10 working points considered in this document. Each WP is defined by a cut value X on the MV2c10 output weight distribution (MV2c10 discriminant $> X$, MV2c10 discriminant values ranging in $[-1, 1]$). The resulting b -tagging efficiency ($\varepsilon_b^{\text{MC}}$), c - and LF-jet rejection rates ($1/\varepsilon_c$, $1/\varepsilon_l$) as measured in a $t\bar{t}$ simulated sample are also shown.

WP	Cut value X	$\varepsilon_b^{\text{MC}}$	c -jet rejection	LF-jet rejection
85%	0.18	85%	3	34
77%	0.65	77%	6	134
70%	0.82	70%	12	381
60%	0.93	60%	35	1539

2 ATLAS detector

The ATLAS experiment [1] at the LHC is a multi-purpose particle detector with a forward-backward symmetric cylindrical geometry and a near 4π coverage in solid angle. It consists of an inner tracking detector surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadron calorimeters, and a muon spectrometer.

The inner tracking detector (ID) covers the pseudorapidity range $|\eta| < 2.5$. It consists of silicon pixel, silicon micro-strip, and transition radiation tracking detectors. Among them, the pixel detector is crucial

¹ ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z -axis along the beam pipe. The x -axis points from the IP to the centre of the LHC ring, and the y -axis points upwards. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z -axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$. Angular distance is measured in units of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$. The transverse energy is defined as $p_T = E / \cosh(\eta)$.

for b-jet identification. A new inner pixel layer, the Insertable B-Layer [12, 13] (IBL), was added before the start of Run 2, at a mean sensor radius of 3.2 cm from the beam-line.

Outside the ID, the lead/liquid-argon (LAr) sampling calorimeters provide electromagnetic (EM) energy measurements with high granularity. A hadron (iron/scintillator-tile) calorimeter covers the central pseudorapidity range ($|\eta| < 1.7$). The end-cap and forward regions are instrumented with LAr calorimeters for both EM and hadronic energy measurements up to $|\eta| = 4.9$. The muon spectrometer surrounds the calorimeters and is based on three large air-core toroid superconducting magnets with eight coils each. Its bending power is in the range from 2.0 to 7.5 T m. It includes a system of precision tracking chambers and fast detectors for triggering.

A two-level trigger system, using custom hardware followed by a software-based level, is used to reduce the event storage rate to a maximum of around 1 kHz.

3 Data sample and event selection

4 Monte Carlo simulation

5 *b*-tagging algorithms

6 Calibration with the negative tag method

7 Calibration with the adjusted Monte Carlo method

8 Comparison between the two methods

9 Conclusion

Acknowledgements

The atlaslatex package contains the acknowledgements that were valid at the time of the release you are using. These can be found in the acknowledgements subdirectory. When your ATLAS paper or PUB/CONF note is ready to be published, download the latest set of acknowledgements from:
<https://twiki.cern.ch/twiki/bin/view/AtlasProtected/PubComAcknowledgements>

Appendix

In a paper, an appendix is used for technical details that would otherwise disturb the flow of the paper. Such an appendix should be printed before the Bibliography.

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Auxiliary material

In an ATLAS paper, auxiliary plots and tables that are supposed to be made public should be collected in an appendix that has the title ‘Auxiliary material’. This appendix should be printed after the Bibliography. At the end of the paper approval procedure, this information should be split into a separate document – see `atlas-auxmat.tex`.